

## CHAPTER 11

# COMPRESSED AIR SYSTEMS

The Utilitiesman is involved in the installation of compressed air systems. The senior UT must be capable of identifying and directing the proper construction techniques for installation of fittings and components. You will also be involved in the maintenance of systems installed previously. In this chapter compressed air systems and air quality

requirements are also discussed.

### SYSTEM CLASSIFICATIONS

Compressed air is a form of power that has many important uses in industrial activities. An air compressor plant (fig. 11-1) is required to supply air of adequate volume, quality, and pressure at the various points of application. Compressed air is stated as pounds per square inch gauge (psig). These plants or systems are classified as

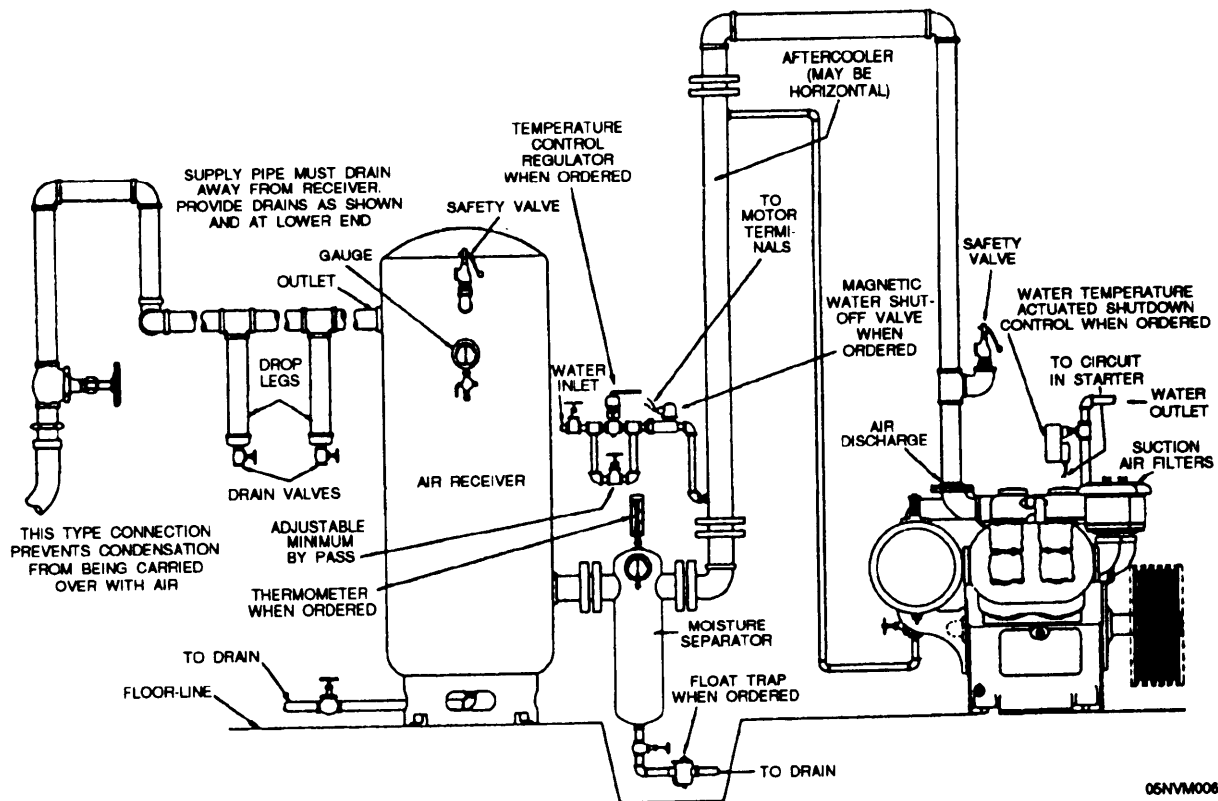


Figure 11-1.—Components of a compressed air plant.

low-pressure (0 to 125 psig), medium-pressure (126 to 399 psig), or high-pressure (400 to 6,000 psig) systems.

### LOW-PRESSURE SYSTEMS

Low-pressure systems provide compressed air up to 125 psig pressure. When you are installing a low-pressure system, pressure is usually reduced at reducing stations for branches requiring lower pressures. Several air pressure requirements for low-pressure air consumers are listed below:

Laboratories	5 to 50 psig
Shops	60 to 125 psig
Laundries and dry cleaning plants	70 to 100 psig
Hospitals	20 to 50 psig
Ordinary service (tools, painting, and so forth)	60 to 80 psig
Soot blowing for boilers	80 to 125 psig

### MEDIUM-PRESSURE SYSTEMS

Medium-pressure systems provide compressed air within the range of 126 to 399 psig pressure. These systems are not extensive and are generally provided with individual compressors located near the loads. Medium-pressure systems are mainly used for the starting of diesel engines, soot blowing of boilers and high-temperature water (HTW) generators, and hydraulic lifts.

### HIGH-PRESSURE SYSTEMS

These systems provide compressed air within the range of 400 to 6,000 psig pressure. Hazards that increase with higher pressures and capacities can be minimized by the use of separate compressors for each required pressure. Systems operating at 3,000 psig may require small amounts of air at lower pressures, which is supplied through pressure-reducing stations.

Caution must be used with high-pressure systems because when high-pressure air enters suddenly into pockets or dead ends, the air temperature in the confined space increases dramatically. If there is any combustible material in the space and the air temperature increases to the ignition point of the material, an explosion may occur. This is known as auto ignition or diesel action. Explosions of this type may set up shock waves that travel through the compressed air system. This travel may cause explosions at

remote points. Even a small amount of oil residue or a small cotton thread may be sufficient to cause ignition.

Some common pressure requirements for high-pressure systems may be as follows:

Torpedo workshop	600 to 3,000 psig
Ammunition depot	100, 750, 1,500, 2,000, and 4,500 psig
Wind tunnels	Over 3,000 psig
Testing laboratories	Up to 6,000 psig

### AIR QUALITY REQUIREMENTS

The quality of air supplied from a compressed air system will vary with application. The installer and maintenance personnel should consider the class of air entrapment and specific air quality requirements for each application.

### CLASSES OF AIR ENTRAPMENT

The classes of air entrapment may be subdivided into inert and chemical particulate, chemical gases, oil, and water. To prevent contamination of an air compression system by these types of entrapments, you should follow certain guidelines for each situation of possible contamination.

#### Particulate

Intake structures or openings should be free of shelves, pockets, or other surfaces that attract and accumulate particulate. Properly designed intakes are large enough to produce a low-velocity airflow. This limits the size of the particles that may be picked up by the intake suction.

Some particulate may contain active chemicals that may form acids or alkalines in the inevitable presence of water. These chemical particulate can accelerate damage to compressor surfaces.

Particulate are sized in microns or micrometers. This measurement is size, not weight. One micron is a unit of length equal to one millionth of a meter. Particles larger than 10 microns are visible to the naked eye. Filter systems are required for all air compressors. Generally, filters should be able to remove particles down to 1 to 3 microns in size.

#### Gases or Fumes

Gases or fumes are fully airborne and generally independent of air velocity. They can

be strong acid, alkaline, or otherwise corrosive to the internal surfaces or lubricants of the compressor. In addition, gases or fumes may be prohibited by the end-use process, such as medical gases or breathing air and for environmental or odor reasons. Intakes near normal flow paths of engine exhausts should be avoided.

## Oil

Oil fumes, vapor, or mist can be as difficult to handle as particulate or gases. Even though many types of compressors are oil lubricated, the oil ingested may not be compatible and compressor load may be increased.

## Water

Waste and water vapor are always present in air intakes. Installation of intakes should prevent the accumulation of free water. Free water ingested into the compressor causes damage to internal components.

Since water vapor with chemical content corrodes steel piping, precautions must be taken to protect materials from corrosion. Galvanizing, applying protective coatings, or using plastic or stainless steel piping for air intakes are some suggested methods to retard or prevent corrosion. Also be sure to install intakes in a manner that excludes rainfall, snow, or spray by applying a weather hood.

## SPECIFIC AIR QUALITY REQUIREMENTS

The diverse uses of air are accompanied by specific air quality requirements. These vary from high purity requirements through the need to introduce materials into a system to be carried along with the air. This section will discuss these specific air quality requirements.

### Commercial Air

Commercial compressed air is graded according to its purity. The purest is grade A running alphabetically to grade J, the least pure. The Compressed Gas Association has set guidelines for the grading of commercial compressed gas. The application of commercial compressed air is varied and generally specified for each individual installation by engineers. The full extent of the quality requirements for commercial compressed air applications can be located in the Compressed Air Association publication *Commodity Specification for Air*, G-7.1 (ANSI 286.1-1973).

### Breathing Air

Breathing air must be of high quality for obvious reasons. Federal Specification BB-A-1034 (fig. 11-2) outlines the specific requirements for breathing air.

Component	Source I (Pressurized Container Air)		Source II (Compressed Air)	
	Grade A	Grade B	Grade C	Grade D
Oxygen (by volume) percent	20 to 22	19 to 23	20 to 22	19 to 23
Carbon dioxide (by volume)	500 parts per million (ppm) max	1,000 ppm max	500 ppm max	1,000 ppm max
Carbon monoxide (by volume)	10 ppm max	10 ppm max	10 ppm max	10 ppm max
Oil (mist and vapor) and particulate matter (weight/volume)	0.005 milligrams (mg) per liter, max	0.005 mg per liter, max	0.005 mg per liter, max	0.005 mg per liter, max
Separated water	None	None	None	None
Total water (weight/volume)	0.02 mg per liter, max	0.3 mg per liter, max (Dew point—20 degrees F.)	0.02 mg per liter, max	0.3 mg per liter, max (Dew point—20 degrees F.)

Figure 11-2.—Breathing air requirements, Federal Specification BB-A-1034A AM 1.

Special attention must be given to eliminating carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), hydrocarbons, odor, and water from breathing air. Carbon monoxide has first priority as its effects are cumulative and very small concentrations can cause problems. Whenever possible, carbon monoxide monitoring should be provided at the compressor intake. This monitoring equipment should sound an alarm or shut down the system when CO is detected.

Carbon dioxide is found in combustion flue gases such as boiler stacks. Do not place compressor intakes near or downwind of the stacks.

Systems should be kept free of oil to limit the possible concentration of hydrocarbons or petroleum products. For breathing air, compressors should be oil free rather than using auxiliary petroleum removal equipment. The heat caused by compression may cause thermal breakdown of oil or an explosion danger may exist as a result of drawing hydrocarbons into the air system.

Water content is kept below saturation to prevent condensation at points that cannot be cleaned. It is recommended that refrigerant or dessicant dryers be used to remove moisture from a breathing air system. This will limit the vapor clouding (fogging) of glasses and visors.

### **Medical Air**

Medical air quality must be the same or better than breathing air. Whatever quality is established must be strictly adhered to.

### **Instrument and Control Air**

Air quality requirements for instrument and control air should place emphasis on cleanliness and low moisture content. The Instrument Society of America (ISA) has established the following requirements:

- Dew point, exterior: 18°F (−7.8°C) below minimum recorded ambient temperature
- Dew point, interior: 18°F (−7.8°C) below minimum interior temperature but not higher than 35°F (1.7°C)
- Particle size: 3 microns maximum
- Oil content: As close to zero as possible but not over 1 ppm

- Contaminates: No corrosives or hazardous gases

Water content must be low enough to prevent condensate accumulations. Special attention should be given to ensure that intake air is filtered and oil or water removed. A refrigerant dryer with a dew point at least as low as 30°F (−1.1°C) is recommended for these services.

### **Aircraft Starting and Cooling Air**

Aircraft starting air requires reasonably clean air to prevent introduction of excessive levels of oil, water, or particulate into engine systems. Normal intake filtering and oil/water separation should be adequate.

Aircraft cooling air is intended for electrical load cooling to prevent malfunction of the equipment. Cooling air should be reasonably clean. This air may also be used for breathing. If it is, then breathing air quality standards should be maintained.

### **Air for Pneumatic Tools**

When compressed air is intended for use with pneumatic tools, it should be filtered for particulate and water should be separated out. Oil is usually required to be ingested into the air for tool lubrication. Mist injection is preferred for tools to ensure dispersion and maximum settlement. Note that pressures in excess of 400 psig may cause compression combustion when oil is present.

### **High-Pressure Air Systems**

Air quality must be carefully analyzed to minimize not only the normal hazards of high pressure, but the internal explosive hazards that exist with high-pressure systems. Of particular danger is the introduction of oil and hydrocarbons during compression and their remaining and accumulating throughout the system. A high-pressure system of 500 psig or higher is subject to rapid local heat buildup whenever there is a rapid filling of a component or vessel. The heat buildup (combined with oil and foreign material) that permits the oil to wick or vaporize can readily cause an explosion or fire. Any explosion in the system may produce several shock waves to travel the system, compounding the damage. Because of this problem, special attention is required to clean the intake air, limit the introduction of

lubrication oil, and remove oil after completion of the compression process.

## **AIR COMPRESSORS AND AUXILIARY EQUIPMENT**

There are basically two types of compressors: positive displacement and dynamic. This section will discuss the reciprocating air compressors, the rotary air compressors, the helical screw compressors classed as positive displacement compressors, and the dynamic centrifugal compressors.

General auxiliary equipment will also be discussed. Auxiliary equipment consists of any device(s) that may be added to the system to improve its efficiency or provide a specific function. It provides a safe condition under which the compressor system will be operating.

### **RECIPROCATING AIR COMPRESSORS**

The most commonly used stationary air compressors are the reciprocating, positive displacement design. They may be single acting or double acting, single stage or multistage, and horizontal, angle, or vertical in design.

In a single-stage unit there is but one compressing element; it compresses air from the initial intake pressure to the final discharge pressure in one step. A multistage machine has more than one compressing element. The first stage compresses air to an intermediate pressure, then one or more additional stages compress it to the final discharge pressure.

In the reciprocating compressor the compression cycle is composed of three phases: intake, compression, and discharge.

During the intake stroke the downward movement of the piston creates a partial vacuum inside the cylinder. The spring-operated intake valve is forced open by the differential pressure between free air on one side and the partial vacuum inside the cylinder. As the valve opens, air fills the cylinder. The piston now moves into the compression stroke, forcing the intake valve closed and raising the pressure of the air trapped in the cylinder. When the pressure of this air is great enough to overcome the force of the

spring-operated discharge valve, the valve opens and the compressed air is discharged from the cylinder.

Compressors are classified as low pressure, medium pressure, or high pressure. Low-pressure compressors provide a discharge pressure of 150 psi or less. Medium-pressure compressors provide a discharge pressure of 151 psi to 1,000 psi. Compressors that provide a discharge pressure above 1,000 psi are classified as high pressure. Note that compressors are classified at different pressures than those for classifying total compressed air systems discussed earlier.

Most low-pressure air compressors are of the two-stage type with either a vertical or a vertical W arrangement of cylinders. Two-stage, V-type, low-pressure compressors usually have one cylinder that provides the first (low-pressure) stage of compression and one cylinder that provides the second (high-pressure) stage, as shown in figure 11-3. W-type compressors have two cylinders for the first stage of compression and one cylinder for the second stage. This arrangement is illustrated in figure 11-4.

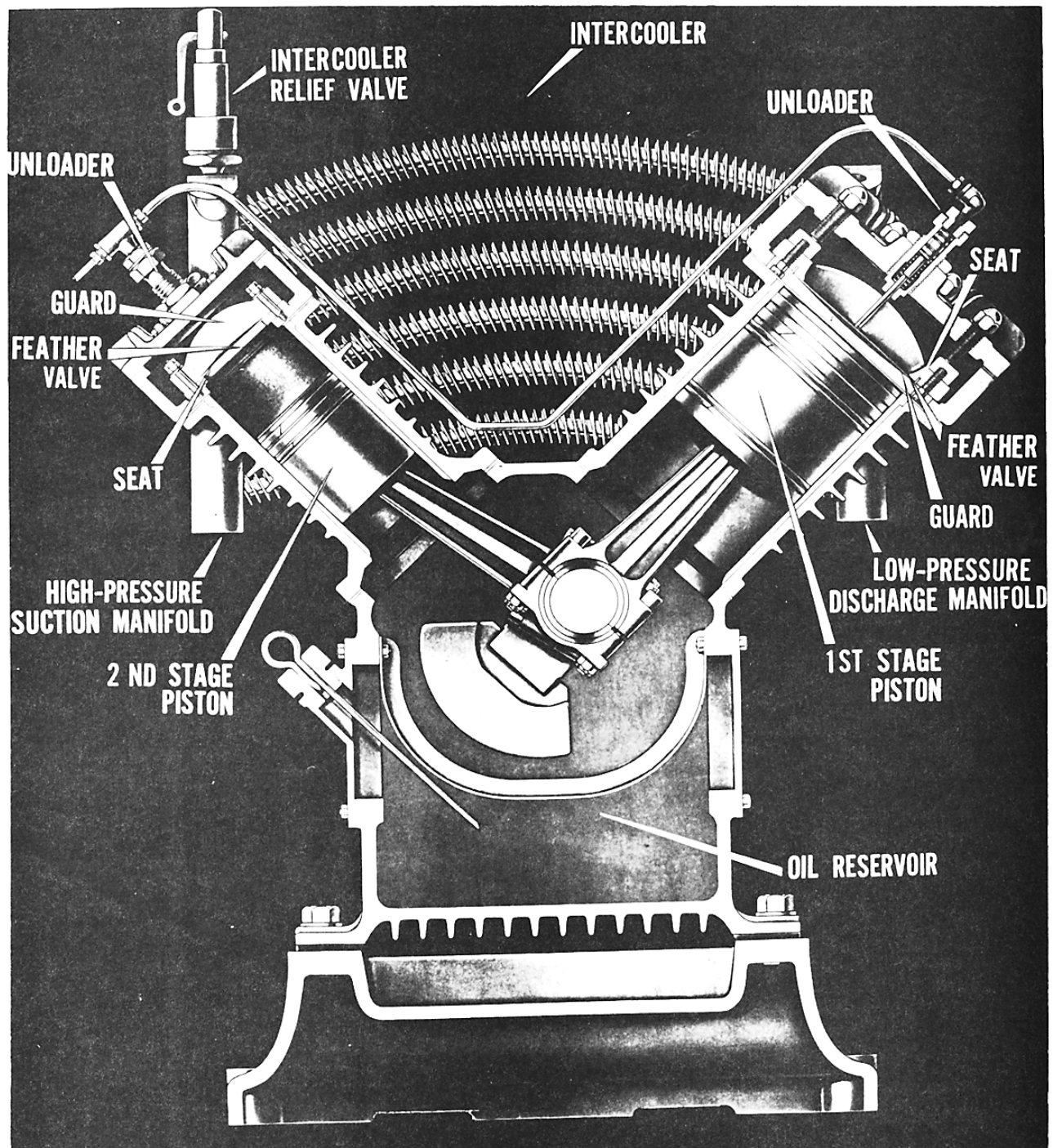
Compressors may be classified according to a number of other design features or operating characteristics.

Medium-pressure air compressors are of the two-stage, vertical, duplex, single-acting type. Many medium-pressure compressors have differential pistons, as shown in figure 11-5. This type of piston provides more than one stage of compression on each piston.

### **ROTARY AIR COMPRESSORS**

Rotary sliding vane compressors are machines in which longitudinal vanes slide radially in a slotted rotor that is mounted eccentrically in a cylinder. The rotor is fitted with blades or vanes that are free to slide in and out of longitudinal slots and maintain contact with the cylinder walls by centrifugal force. In operation, as the blades are forced outward by centrifugal force, compartments are formed in which air is compressed (fig. 11-6). Each compartment varies from a maximum volume on the suction side of the revolution to a minimum volume on the compression half of the revolution. This gives a positive displacement-type suction and pressure effect.

Another type of rotary compressor is the twin-lobe unit sometimes referred to as a blower

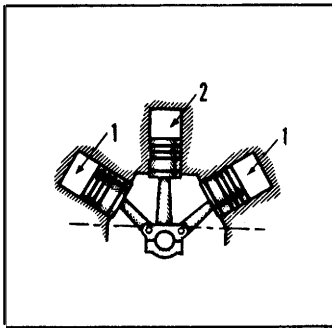


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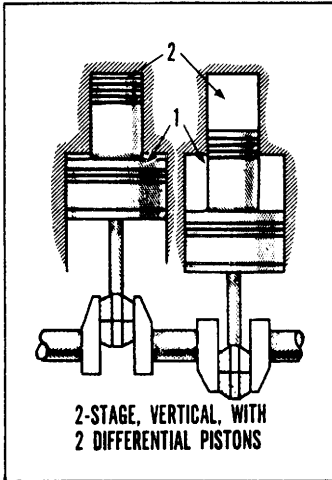
**Figure 11-3.—A typical two-stage reciprocating low-pressure air compressor.**

(fig. 11-7). This unit consists of two impellers mounted on parallel shafts that rotate in opposite directions within a housing. As the impellers rotate, they trap a quantity of air themselves and the blower housing and move the air around the casing to the discharge port.

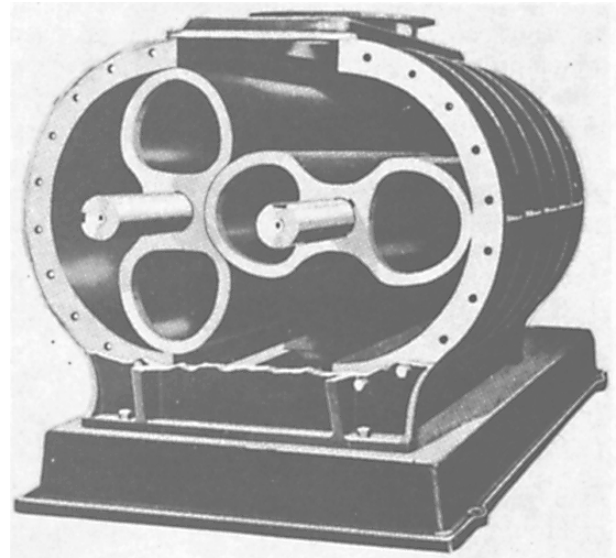
This action takes place twice each revolution of an impeller and four times per revolution of both impellers. The impellers are positioned in relation between to each other by timing gears, located at the end of each shaft and external to the blower housing.



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Figure 11-4.—W-type, two-stage, three-cylinder arrangement.



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Figure 11-5.—Differential piston with a two-stage, vertical arrangement.



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Figure 11-7.—Twin-lobe rotary compressor.

You should always use maintenance and service literature provided by manufacturers when you are working with rotary compressors. Maintenance information is given in *Operation and Maintenance of Compressed Air Plants*, NAVFAC MO-206.

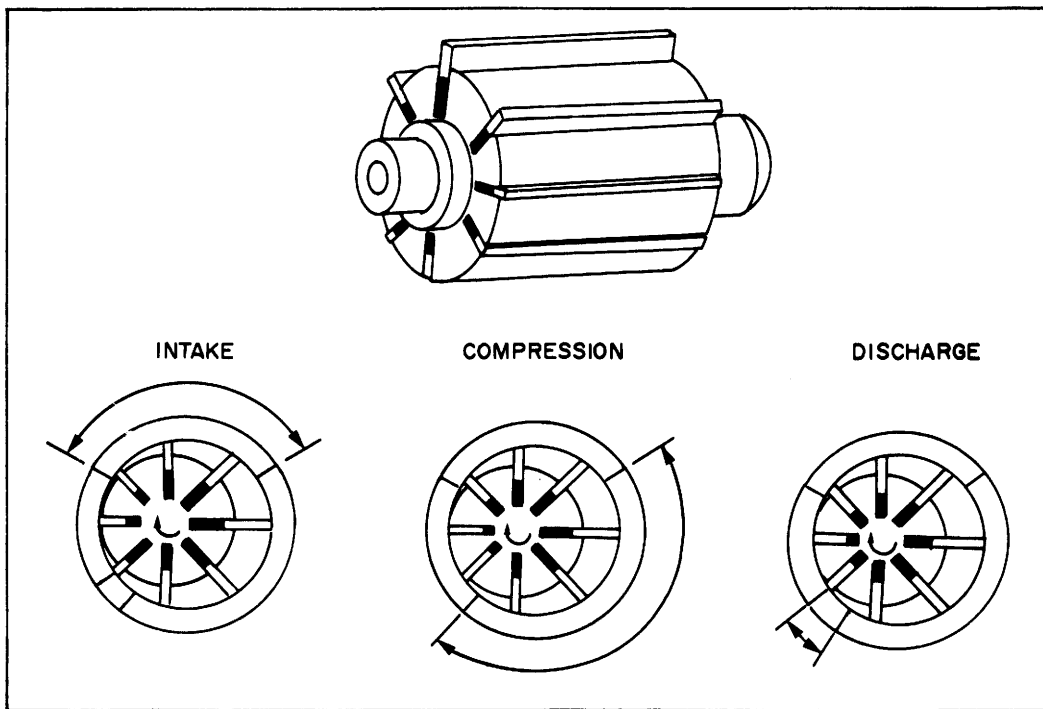


Figure 11-6.—Compression cycle of rotary compressor.

## HELICAL SCREW COMPRESSORS

Helical screw compressors contain two mating rotating screws, one locked and one grooved, which provide the driving force. The unit's screws take in air, decreasing its volume as it progresses in a forward-moving cavity toward the discharge end of the compressor. Figure 11-8 shows a typical single-stage compressor and a double-stage helical screw compressor. These compressors are best used in booster or near constant-load conditions at low-pressure, oil-free application. Helical screw compressors may also be found in aircraft start facilities.

## DYNAMIC CENTRIFUGAL COMPRESSORS

Dynamic compressors are high-speed rotating machines in which air is compressed by the

action of rotating impellers or blades that impart velocity and pressure to the air. Figure 11-9 shows the internal parts of a multistage centrifugal compressor. This type will deliver air at an essentially constant pressure over a wide range of capacities. The direction of airflow is radial with respect to the axis of rotation.

Centrifugal compressors have a lower limit of stable operation called the surge point. Operation below this point results in pumping or surging of the airflow. Prime movers are normally electric motors or steam turbines.

Centrifugal compressors are intended for near continuous industrial air service when the load is reasonably constant. These compressors also work well when oil-free air is required and can be used for breathing air.

Table 11-1 shows typical application recommendations for both positive displacement and dynamic class compressors.

## AUXILIARY EQUIPMENT

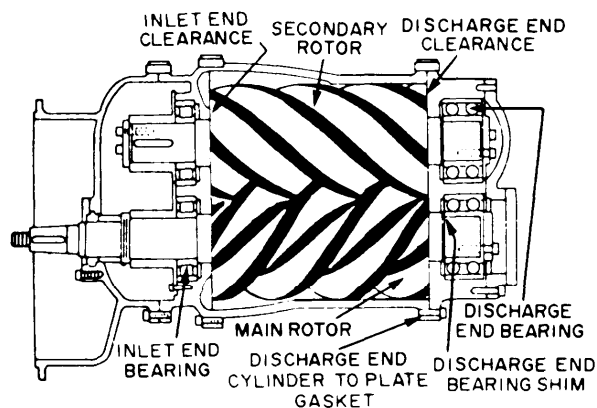
A system that functions to provide a continuous supply of usable compressed air requires certain auxiliary devices in addition to the air compressor. Most compressed air systems require a minimum of auxiliary equipment that should include air intakes, intake filters, silencers, intercoolers, aftercoolers, air discharge systems, separators, dryers, receivers, and so forth. These auxiliary equipments will be discussed in this section in addition to less common auxiliary equipment.

### Air Intakes

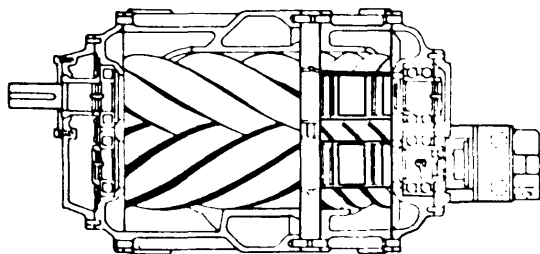
Air intakes should be located high enough to eliminate intake of particles of dust, smoke, dirt, water, and snow. Carbon monoxide sources should not be able to discharge into compressor intakes. Special attention should be given to the elimination of flammable fumes into the compressed air system.

Whenever air intakes must be placed through a roof that is surrounded by parapets, they should be 8 to 10 feet above the roof.

Noise may be generated by air intakes and must be considered during installation. Reciprocating compressors are most likely to develop resonance through intake piping. If this possibility exists, the use of intake dampeners or surge chambers will help. High velocities present noise level problems. Intake pipe velocities should be limited to 1,000 fpm in open areas or 350 fpm across filters. Acoustical silencers combined with filters and/or pulse dampeners are available and



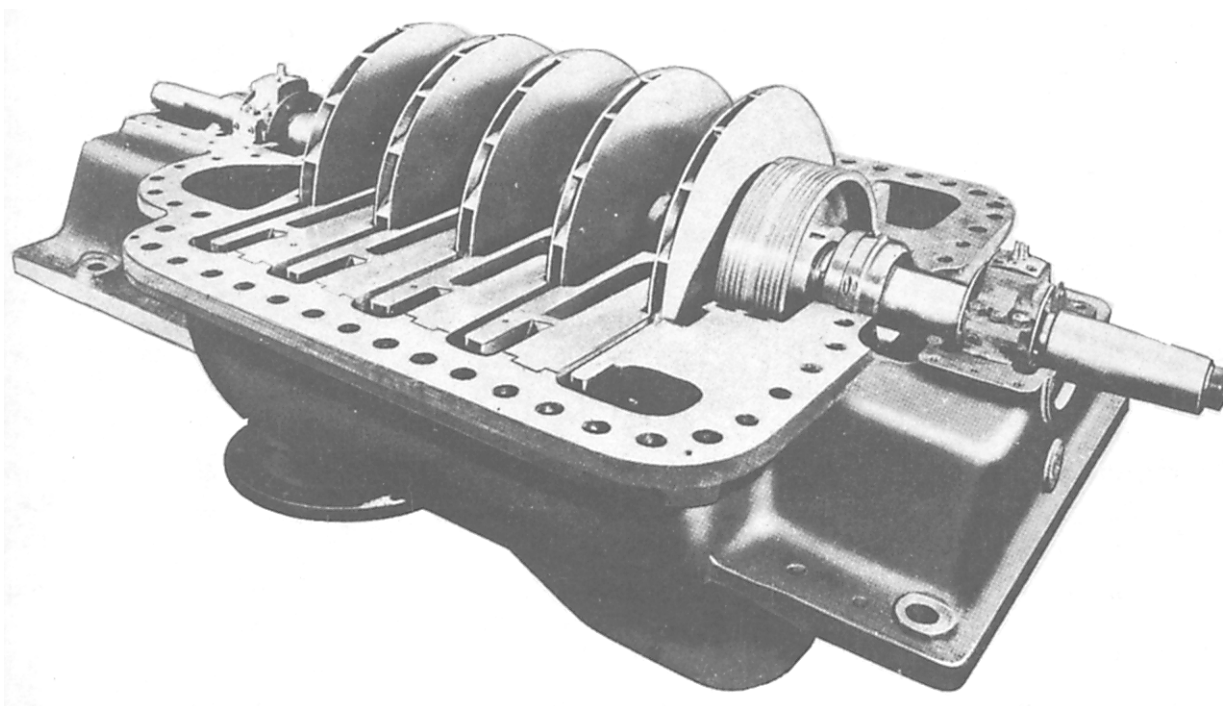
TYPICAL SINGLE-STAGE DESIGN



TYPICAL TWO-STAGE DESIGN

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Figure 11-8.—Rotary helical screw compressors.



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**Figure 11-9.—Internal view of a multistage centrifugal compressor.**

**Table 11-1.—Summary Application Recommendations, Types of Compressors**

Type	Air* Delivery Quality	Pressure Range scfm Range Horsepower Range	Remarks
Reciprocating, single-stage, air cooled	L	100-125 psig, to 50 scfm, to 10 hp	Intermittent light duty
Reciprocating, two-stage, air cooled	L	100-125 psig, to 200 scfm, to 50 hp	Low volume requirements
Reciprocating, two-stage, air cooled	N	100-125 psig, to 50 scfm, to 15 hp	Low volume requirements
Reciprocating, two-stage, water cooled	L	100-150 psig, 400-1,000 scfm, 75-200 hp	Wide application range
Reciprocating, two-stage, water cooled	N	100-125 psig, 400-1,000 scfm, 75-200 hp	Wide application where required
Reciprocating, two-stage, water cooled, duplex and/or double acting	L	100-150 psig, 1,000-5,000 scfm, 200-1,200 hp	High volume requirements
(1 psig = 6.90 kPa gauge, 1 scfm = 0.0268 m <sup>3</sup> /min, 1 hp = 0.746 kW)			
*L—Lubricated			
N—Nonlubricated			

**Table 11-1.—Summary Application Recommendations, Types of Compressors—Continued**

Type	Air* Delivery Quality	Pressure Range scfm Range Horsepower Range	Remarks
Reciprocating, multi-stage, water cooled	L, N	150-6,000 psig, 10-100 scfm, 3-1,000 hp	Medium and high pressure
Rotary, sliding vane, single-stage	L, N	5-50 psig, 50-3,000 scfm, 0.5-300 hp	Match to load only pressure booster
Rotary, sliding vane, two-stage	L, N	60-100 psig, 100-3,000 scfm, 15-500 hp	Match to load only pressure booster
Rotary, sliding vane, single- or two-stage oil injected	L	80-125 psig, 120-600 scfm, 15-200 hp	Wide application range
Helical screw, single-stage, lubricated	L	To 35 psig, 30-12,000 scfm, to 1,200 hp	Match to load only single rating point
Helical screw, two stage lubricated	L	60-100 psig, 30-12,000 scfm, to 2,000 hp	Match load only. Single rating point. Aircraft air start. Aircraft cooling
Helical screw, single-stage, oil injected	L	To 125 psig, 40-1,500 scfm, 10-400 hp	Wide application range
Dynamic, centrifugal, single-stage	N	To 35 psig, 1,500-15,000 scfm, 100-1,000 hp	Match load
Dynamic, centrifugal, two-stage	N	35-70 psig, 1,500-15,000 scfm 100-2,000 hp	Match load, breathing air
Dynamic, centrifugal, three-stage	N	70-125 psig, 1,500-15,000 scfm, 200-3,500 hp	High volume requirements, breathing air
Dynamic, centrifugal, four or more stages	N	125 psig or more, 1,500-15,000 scfm, to 3,000 hp	Medium pressure high volume
Dynamic, axial or radial barrel, multi-stage	N	200 psig or more, 1,500 scfm or more, high horsepower	Medium and high pressure, high volume
(1 psig = 6.90 kPa gauge, 1 scfm = 0.0268 mm <sup>3</sup> /min, 1 hp = 0.746 kW *L—Lubricated N—Nonlubricated			